Simulations Of Atmospheric Flows In The Boundary Layer Over Inhomogeneous Surface Conditions

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LONG TERM GOALS

The goal of this project is to improve the description and prediction of resolvable and subgrid-scale atmospheric fields over inhomogeneous surfaces and to develop an integrated modeling system for weather phenomena and dispersion effects on a variety of spatial and temporal scales.

OBJECTIVES

Specific objectives include: 1) test the nonlocal mixing parameterization using a Large-Eddy Simulation (LES) model and incorporate it into a mesoscale model, 2) further develop the Lagrangian random particle dispersion model and test its turbulence parameterization, and 3) further develop a system for evaluating atmospheric models using tracer measurements. This work is supported by the Office of Naval Research, Marine Meteorology and Atmospheric Effects.

APPROACH

We have tested the parameterization of nonlocal mixing by using a fully compressible cloud-resolving model (Koracin et al. 1998a) and a LES (Moeng (1984), and Andren (1995)). The nonlocal parameterization was incorporated into the higher-order turbulence-closure mesoscale model (Tjernström and Koracin 1995). The Lagrangian random particle (LAP) model (Isakov 1998, Koracin et al. 1998b) was further developed with respect to its treatment of the transport and dispersion of quasi-inert toxic gas (Koracin et al. 1999a). The "Tracer Potential" method (Koracin et al. 1998e, 1998f, 1998c, 1999b, and 1999c) was compared with a statistical method which takes into account the spatial distribution of simulated and measured concentration patterns.

WORK COMPLETED

A series of LES runs was performed with 3 different conditions: an initial convective profile and initial heat flux of zero, only non-zero heat flux, and a simultaneous effect of both the convective profile and the heat flux. The initial and final (well-mixed) profiles were then used to calibrate the nonlocal mixing parameterization.

The incorporation of the nonlocal mixing scheme into the mesoscale model was performed by using the concept of the equilibrium potential temperature after the completion of mixing and the nudging of the values of the results predicted by the local-closure model.

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Sensitivity tests were performed to determine the impact of various levels of turbulence intensity on dispersion estimates.

The "Tracer potential" method has been compared with the Figure of Merit approach (Klug et al. 1992). The comparison was performed using the Project MOHAVE data (Green 1998, Koracin et al. 1999d).

RESULTS

The LES domain consisted of 80 x 80 x 80 points with a resolution of 37.5 m x 37.5 m x 15 m. The base and top of the inversion were set at 850 and 1150 m, respectively. A surface heat flux of 30 W/m^2 was assumed. At 5400 seconds after the simulation start, a quasi-steady convective boundary layer was modeled. In that instance, the external heating aloft was imposed for the next 1200 s. This idealized heating loosely resembles how the strong heating aloft can create inhomogeneities within the boundary layer and a decoupling of the boundary layer with respect to the turbulence structure. Figure 1 shows vertical profiles of the potential temperature at different iteration steps as estimated by the nonlocal scheme and the LES. In spite of non-treatment of heat flux at the surface and entrainment at the top of the boundary layer, the nonlocal scheme was able to successfully reproduce the mixing processes that were simulated by the LES.

In order to examine the differences between the two-dimensional and three-dimensional representations of tracer transport, we have tested an area enclosing estimated trajectories at the surface, source height, and the most probable plume height levels with respect to an area of surface concentrations greater than a given threshold. The concentrations were predicted by the Lagrangian random particle model (Koracin et al. 1998b; 1999a) using the three-dimensional MM5 wind field as input. Following Klug et al. (1992), we compared the trajectory-enclosed area with the surface area of simulated concentrations. The simulated and trajectory-enclosed areas are denoted as S and T, respectively. The level of agreement is then defined by the Figure of Merit in Space (FMS),

$$FMS = \frac{S \cap T}{S \cup T}$$

where the term in the numerator is the cross section between the area of simulated concentrations and the trajectory-enclosed area, while the term in denominator is the union of both the area of simulated concentrations and the trajectory-enclosed areas. The FMS ranges from 0 (no agreement) to 1 (perfect agreement). We calculated the FMS for the Project MOHAVE data for three levels. The FMS was relatively high for this limited sample, ranging from 0.38 to 0.67, 0.35 to 0.5, and 0.32 to 0.50 for the surface, source height, and the most probable plume effective height, respectively. A possible reason for this relatively good comparison is that there was generally sufficient vertical mixing and small directional shear.
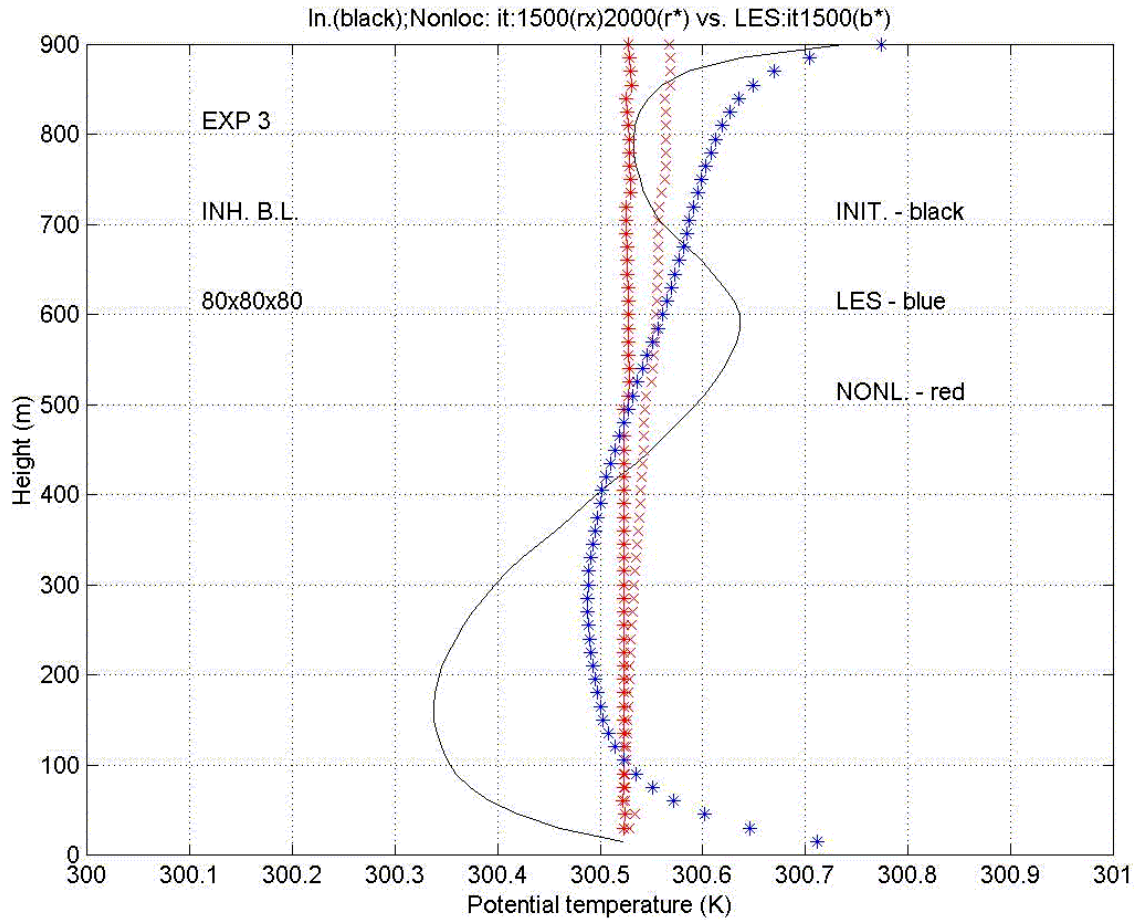
Figure 1: Vertical profiles of the initial potential temperature (black solid line)and final temperature as simulated by the LES (blue asterisks), as well as intermediate (red x) and final (red asterisks) temperature as obtained from the nonlocal scheme.

IMPACT

The models and methods we have developed will both increase understanding of and lead to improved prediction of the atmospheric boundary layer, particularly in the areas of turbulence transfer and atmospheric transport and dispersion. This has an obvious application to naval and aircraft operations as well as to defenses against chemical or biological weapons. Most of the models can be operated on a PC platform, permitting use by tactical military units.

TRANSITIONS

A team from the University of Uppsala (Mr. Ragoth Sundarajan) and University of Stockholm (Dr. Michael Tjernstrom) in Sweden is using our developed Lagrangian random particle model to simulate marine intrusion events along the west coast. Drs. Michael Tjernstrom and Gunilla Svensson of University of Stockholm are using our method of nonlocal mixing in a collaborative study of the ASTEX

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data, as well as to analyze the cloud-resolving and LES results. Dr. Leif Enger from the same institution is developing a method of evaluating dispersion models based on our Tracer Potential method of evaluating atmospheric models. We are also planning to use our Tracer Potential method in the ONR-NRL project related to development of VLSTRACK routines using the COAMPS model results. Together with Dr. Steve Chai (DRI) and Dr. Leif Enger (University of Uppsala, Sweden) we are using our Tracer Potential method and our developed Lagrangian random particle model to study the transport and dispersion of tracers in complex terrain. A significant collaboration has been initiated with Dr. Marek Uliasz (CSU-ASTER) for inter-comparing our LES results with the RAMS-LES and developing further experiments in turbulence evolution and analysis of asymmetric nonlocal matrices of mixing over inhomogeneous surfaces and within inhomogeneous boundary layers.

RELATED PROJECTS

Work on this project benefited from work on and results from another ONR-funded project (N00014-96-1-0980) which focused on simulations of coastal dynamics. Darko Koracin is also a P.I. on this project. Performance has been enhanced by collaborations with Dr. Michael Tjernström of the University of Uppsala, Sweden and Dr. Marek Uliasz (CSU-ASTER). Research conducted in this project led to a proposal funded by DOD-ONR (Drs. Steve Chai and Darko Koracin) focusing on modeling the dispersion of vapor and aerosol particulates in complex terrain. The "Tracer Potential" method and the LAP model were also used in several EPA-related projects and in the NOAA-funded weather modification program (see website). The P.I. on this project is also a P.I. (with co P.I.s Drs. Steve Chai and Melanie Wetzel, and Mr. Jeff Tomer) on a project entitled "Enhancement of high-resolution numerical simulations of atmospheric and dispersion processes using a multi-processor computer," which was awarded by DoD-DURIP.

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